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Art. XIX.—*On the Occurrence of Igneous Pebbles in a Conglomerate of Upper Silurian Age from near Walhalla.*

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(With Plate II.)

[Read 12th November, 1914].

Introduction.

During a short visit made to Walhalla in June, 1913, with the primary purpose of studying the relations between the auriferous quartz reefs and the intrusive rocks there, my attention was drawn, through the medium of a description in Mr. Herman's report on the Walhalla Gold-field,[1] to an interesting conglomerate, containing pebbles of igneous rocks, which was interbedded with limestones, shales and grits of Yeringian age. It was at once evident, from a cursory examination of the conglomerate, that Mr. V. R. Stirling's idea[2], of an immense fault and associated fault breccia was untenable; and further that the igneous pebbles had no genetic connection with the so-called diorite dykes which are so characteristic a feature at Walhalla.

Many of the pebbles showed very little in hand specimens, and it was only after sectioning them that their interesting nature was revealed. Unfortunately, the time at my disposal was rather limited, and my examination of the conglomerate and collection of pebbles were not as detailed and thorough as they might have been.

Previous Literature.

In 1878, Mr. R. A. F. Murray[3] noted the presence of grits associated with the limestone near the Thomson river, but did not mention the occurrence of igneous detritus in the grits.

In 1899 Mr. V. R. Stirling[4] described a belt of breccia occurring near the Thomson river copper mine. According to him

1 "Report on the Walhalla Gold-Field." Spec. Rept. Dept. Mines, Vict., 1901.

2 "Notes on alleged Copper Occurrences at Cooper's Creek." Monthly Prog. Rep. Vict. Geol. Surv., No. 2, 1899.

3 Prog. Rep. Vict. Geol. Surv., No. 5, p. 47.

4 "Notes on alleged Copper Occurrences at Cooper's Creek." Monthly Prog. Rep. Vict. Surv. No. 2, 1899.

it consisted of sub-angular and rounded fragments of quartzite, decomposed diorite, limestone, etc., in a dark-coloured siliceous matrix in part calcareous, and was associated with a decomposed dyke and a belt of limestone. He concluded from the following evidence :—

(a) The direct association of the breccia with the decomposed dyke;

(b) The appearance of presumably the same belt of breccia and dyke, first, on one side of the limestone, and then on the other;

(c) The occurrence of included fragments of limestone in the breccia;

that the breccia was probably of volcanic origin, occupying an immense strike fault in the silurian rocks.

In 1901, Mr. H. Herman[1] described in some detail the relations between the beds near the Thomson river. He states that "A gradual transition in texture can be traced from the coarse fossiliferous conglomerate . . . through fossiliferous shales with crinoid stems, to highly calcareous encrinital shales, and finally to encrinital limestone or marble." He regarded the conglomerate as a normal shore line deposit, and explained the presence of limestone pebbles in it, as either due to contemporaneous erosion or thought possibly that they may have been derived from a pre-existing formation. Mr. F. Chapman[2], in 1907, described the fossils occurring in the limestone near the Thomson River copper mine. He mentioned the occurrence of flakes of biotite and chlorite, and contorted bands of tuffaceous andesitic ejectmenta, in sections of the limestone, and suggested that volcanic activity took place contemporaneously with the deposition of the limestone.

Field Relations near the Thomson River, Walhalla.

The Silurian sediments near Walhalla[3] consist lithologically of sandstones, shales and slates, for the major part, but lenticular bands of limestone associated with gritty and conglomeratic beds are not unusual. The structure is geosynclinal with thin bedded, highly cleaved, shales and slates in the centre of the geosyncline, and more coarsely grained sandstones and gritty beds towards the margins.

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1 Op. cit., p. 12.

2 "The fossiliferous limestones and conglomerates of the Thomson and Tyers rivers and Marble creek, Gippsland." Records Vict. Geol. Surv., vol. ii., pt. 1.

3 For geological map and sections of the locality dealt with, vide Herman, op. cit.

Near the Thomson River copper mine the beds dip easterly, at angles between 50° and 70°, and strike N. 15° E. to N. 20° E.; and the general stratigraphical succession, from the west to east, starting from a point about half a mile west of the Thomson River, is as follows:—

(1) Normal shallow water marine sediments chiefly shales and sandstones.

(2) A band of conglomerate and gritty beds, well seen in sections on the track from the Copper Mine township to the Jubilee Mine, and also in cuttings near the limestone quarries in Cooper's Creek.

(3) Overlying these conglomerates and fossiliferous grits in the Cooper's Creek section, occurs a lenticular mass of dense black limestone, highly fossiliferous, and traversed by veins of calcite. The limestone matrix weathers more rapidly than the fossils, and as a result the latter are often seen in fine relief on the weathered surface of the rock. The forms present are chiefly corals, crinoids, brachiopods, and polyzoa, and they are very similar to the fossils occurring in the Yeringian limestone at Lilydale. Bedding is not very evident in the massive limestone, but occasional shale bands serve to define it. This band of limestone is not present in the section along the road from the Copper Mine township to the Jubilee Mine. The corresponding strata, in this section, overlying the conglomerate, consist of grits and calcareous shaly beds, and one or two narrow bands of black, honeycombed chert, which undoubtedly replaces fossiliferous gritty beds.

4. Another outcrop of similar black limestone occurs not far east of the above mentioned beds. At the time of my visit to the locality, it was being quarried immediately to the north of Cooper's creek, near its junction with the Thomson river. This patch of limestone does not extend far to the south, for sections on the same line of strike at the Thompson River show that the massive limestone is absent, and that its place is taken by calcareous, fossiliferous grits containing pebbles of quartzite, and limestone nodules composed in some cases almost entirely of corals. No igneous pebbles were seen by the writer in this conglomerate.

Pebbles of igneous rocks are very numerous in the first mentioned conglomerate. The majority of these pebbles are well-rounded, and they are generally small, being rarely more than three inches in diameter, although Mr. Herman mentions that pebbles up to 6 inches or 8 inches in diameter, are occasionally present. They are partly set in a fine brownish coloured, granular matrix, resembling decomposed igneous material. The pebbles appear to be chiefly volcanic, but occasionally coarsely crystalline rocks, plutonic and metamorphic in character, are seen. According to Mr. Herman[1] diorite pebbles are predominant; but in my limited examination I came across no such pebbles. Microscopical examination of thin sections of these rocks shows that many of them are closely related to one another; and in the specimens collected by the author, all stages are represented between hornblende diabase, and the spherulitic facies of the same rock, or variolite. No acid igneous rocks, either plutonic or volcanic, were found.

Section near the steel bridge over the Thomson river, about two miles north of its junction with Stringer's Creek:—The river, which has followed the strike of the sediments for some considerable distance below here, at this point, cuts across the strike, and good sections are available, especially so on the east bank of the river where cuttings made by the Long Tunnel Company for a tram track, have uncovered the sediments.

Fossiliferous grits and calcareous beds with occasional patches of limestone occur at intermediate points between Cooper's Creek and the steel bridge, and are again present further north of this point. These outcrops are all in east dipping beds, and are on the same line of strike as the Copper Mine series of limestones and conglomerates, and are undoubtedly the northern continuation of the same beds.

The section, near the steel bridge, shows that the beds consist of hard, indurated black and grey, fine grained sandstones and shales, interbedded with well cleaved slates, and coarse grit bands and conglomerate; all dipping east at 50° to 70°. The beds throughout the section are calcareous, and locally contain highly fossiliferous lenticles and nodules of limestone. A fairly gradual passage can be traced from gritty sandstones into coarse fossiliferous grit and conglomerate. The grits are often honeycombed owing to the removal of the fossils. In the more calcareous beds the fossils are preserved in their original calcareous matrix. Corals (Favosites chiefly) and crinoids appear to be the most common fossils in these beds.

The band of conglomerate is well seen on the north side of a small creek entering the Thomson River from the east. Pebbles of quartzite are most common in this conglomerate, and igneous

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1 Op. cit., p. 12.

pebbles are not numerous. Others of vein quartz, sandstone, slate, limestone and rarely chert were found by the writer. These pebbles are usually small and rounded. Some of them are well jointed by planes perpendicular to their longest axes, and these joint planes are occasionally covered with a film of pyrites. Undoubtedly this conglomerate, like the one near Cooper's Creek, is a normal marine shore line deposit.

The author saw no evidence anywhere of the immense fault referred to by Mr. Stirling, and he feels convinced that no such fault exists. No slickensides or gouges were seen; and the shape of the pebbles does not support the view that they have originated by faulting. No great disturbance of the strata has taken place, and there is no evidence of any displacement of the beds. The petrological characters of these pebbles disprove of the idea that they were formed by the brecciation of the associated dyke, referred to by Mr. Stirling, and forcibly suggest that they were derived from pre Upper Silurian igneous rocks. The only series of volcanic rocks in Victoria, known to be pre Silurian in age, are the Heathcotian, and hornblende diabase and associated pyroclastic rocks are characteristic of this series. The pebbles of gneiss in the conglomerate must, undoubtedly, have come from the pre Cambrian metamorphics of eastern Victoria, and the large felspar crystals, referred to by Mr. Stirling[1], may have come from the same source.

Further, Mr. Stirling's strong point of the occurrence of the breccia first, on the east side of the limestone near the Copper Mine township, and on the west side of it further south, can be explained away when it is recognised that the limestone bands are lenticular, and are not persistent in strike, and that there may be two or more lenticular patches of limestone not quite on the same line of strike.

Moreover, the evidence at hand does not support Mr. Chapman's belief in contemporaneous andesitic vulcanicity. It seems to me more probable, as Professor Skeats[2] has suggested, that the volcanic debris included in the limestones, is detrital. The associated conglomerates and grits contain abundant, undoubtedly detrital, igneous pebbles, and it is quite natural to expect that some of this material should be deposited with the limestones. The field relations do not lend any support to Mr. Chapman's sugges-

1 Op. cit.

2 "The Volcanic Rock of Victoria." Pres. Add., Sect. C., Aus. Assoc. Adv. Sci., 1909.

tion, and therefore, inferences drawn from the results of a microscopic examination of thin sections of these rocks, must be accepted with caution. Associated interbedded lavas or tuffs are absent, and the igneous fragments present in the limestone can be most easily explained on the assumption that they were derived from the same source as the detrital igneous pebbles. No indubitable Silurian igneous rocks have been recognised in Victoria, and more definite evidence than that brought forward by Mr. Chapman, is needed to establish Silurian vulcanicity. The present writer agrees with Mr. Herman that the conglomerates and grits are normal shore line deposits, and that the included igneous pebbles are derived from pre-existing formations.

Petrology.

Hornblende gneiss.

Specimen W1, pebble in conglomerate, section on road to Jubilee Mine.

The hand specimen of the rock is coarse grained. Felspar and hornblende can be recognised megascopically.

Examined microscopically, the rock shows very well the effects of mechanical dynamic metamorphism. Strain polarisation has been developed in the quartz grains, and they are considerably mylonitised. The horneblende is almost entirely light green actinolite. The prisms and plates of this mineral are very rarely idiomorphic, and are often twisted and bent in all directions. The elongation of the hornblende crystals is parallel to the direction of foliation of the rock. They are occasionally twinned according to the usual law; with twin and composition plane 100. One idiomorphic basal section showed an excentric emergence of an optic axis. Determination of the axial plane showed that it bisected the obtuse angle between the cleavages, and that it was parallel to the clinopinacoid, as is usual for hornblende. It is moderately pleochroic, giving the following colour scheme:—

X light yellow green.

Y light green.

Z bright green, and $Z > Y > X$ as usual.

The maximum extinction angle from the prismatic cleavage is 15°. The felspar is greatly kaolinised, and has suffered a considerable amount of mechanical deformation. Plagioclase appears to be in excess of orthoclase. The refractive index of the plagioclase is at times greater, and at other times less than that of the quartz, and hence it appears to be oligoclase or oligoclase-andesine. Sphene is not uncommon as irregular shaped dusty masses. Rarely it is present as double wedge shaped crystals. A little chlorite occurs replacing the hornblende; quartz is not abundant. Apparently the original rock was an intermediate plutonic rock.

Hornblende diabase (*Epidiorite*).

Section W2. Pebble in conglomerate near the Thomson River copper mine, is a holocrystalline, fairly even grained rock with pilotaxitic fabric. There is a tendency towards an ophitic texture in places, but it is never very pronounced. Plagioclase and actinolite constitute almost the whole rock, but there is also a little quartz, ilmenite, chlorite and zircon present. The actinolite occurs usually in anhedral grains and masses. It is moderately pleochroic, varying in colour from light green to almost colourless. It is ophitically penetrated by the felspar in places. Most of the felspar laths are either simply twinned, or untwinned. Owing to their extensive sericitisation, it is frequently impossible to determine their original characters. Extinction angles as high as 35° from the twin planes were measured on certain felspars, indicating a rather basic labradorite. Interesting outgrowths have taken place around the original felspar laths. Their idiomorphic outlines are generally visible as greatly altered cores, surrounded by a clear outer zone of albite showing ragged boundaries.

One interesting case, of additional material being added to a former idiomorphic crystal of felspar at two different periods, was visible in this section. By the first addition the idiomorphic crystal became rectangular in outline. Both the original crystal and the added material were now completely sericitised, and a second marginal addition of pellucid felspar took place. The twinning of the original felspar extends through the clear exterior zone, showing that the addition has been in crystallographic continuity with the primary felspar. The method of formation of these outgrowths has been masked in the present case by the great changes undergone by the rock. Professor Judd,[1] from a study of similar outgrowths on felspar crystals from the Western Isles of Scotland and elsewhere, came to the conclusion that the majority of such additions took place whilst the felspars were fresh and unaltered, and that in the Scotch case the outgrowths took

1 Quarterly Journal of the Geological Society, London.

place at the expense of the original glassy ground mass. He mentions that in certain specimens of rocks from New South Wales received by him from Professor David, the outgrowths apparently took place after advanced kaolinisation of the original crystals. In the Walhalla specimens, the latter remarks apply equally well, with the substitution of sericitisation for kaolinisation.

A moderate amount of interstitial quartz, containing fluid and glass inclusions, is present in this section. It is doubtful whether the quartz is primary or not. Considerable changes have taken place in the rock, and it is possible that the quartz was formed at the time of the amphibolitisation of the original femic mineral which was probably augite. A little chlorite (pennine) occurs replacing the hornblende, specimen W4, from same locality as W2. This rock resembles the preceding one very closely. Quartz however is rare. Sub-ophitic hornblende, and plagioclase laths predominate. The plagioclase appears to be present in two generations. An analysis of this rock for silica and alkalies gave the following result :—

SiO_2	52.99	per cent.
K_2O	2.09	per cent.
Na_2O ...	3.21	per cent.

The analysis confirms the microscopical determination of the rock as a hornblende diabase, or according to Harker's nomenclature, a hornblende dolerite. Since the hornblende is secondary, presumably replacing augite, the rock may be described as an epidiorite. No unequivocal potash felspar is present in the section, so that the relatively high percentage of potash indicated in the analysis, is probably due to the extensive sericitisation undergone by the original felspars.

Basic spherulite (? variolite).

In hand specimen, this rock is compact and aphanitic, and green in colour. No vesicles are seen even with the aid of a lens, and in only one specimen collected was there any evidence of varioles.

Section W6, pebble in conglomerate; section on road to the Jubilee Mine. Examined microscopically, it is seen that the rock is composed almost entirely of beautifully developed, sheaf and fan like, and occasionally spherulitic aggregates of hornblende and felspar. Phenocrysts are practically absent, as are also true varioles marked off from the ground mass. According to the definition of Professors Cole and Gregory,[1] "a variolite is a devitrified spherulitic tachylyte, typically coarse in structure." The latter phrase of which was interpreted by Miss Raisin[2] to probably mean that spherulites were visible macroscopically. The Walhalla rock therefore differs from the typical variolite in the absence of macroscopically visible spherulites or varioles. The hornblende is entirely actinolite, and it usually occurs as long microlites frequently crossing one another. Examined under the high power, many of these microlites are seen to be skeleton crystals, and they very often enclose a tubular core of ground mass material showing very low polarisation colours. The edges of the microlites are often greatly serrated, and they usually fork at the ends, and pass gradually into the ground mass of the rock. Cross sections of these laths of actinolite occur in the form of small parallelograms, with central inclusions, corresponding to the tubular inclusions present in the microlites. The actinolite laths show a characteristic cross fracture at right angles to their length, and more rarely a cleavage parallel to their elongation. Twinning according to the usual law is not infrequently present. Both these microlites and the spherulites appear to be essentially contemporaneous in origin. At times the laths intersect the spherulites, but often the reverse is true, and the spherulites cut across, or project into the actinolite laths. Chlorite replaces much of the actinolite. The felspar laths give maximum extinction angles of 25°. They exhibit undulose extinction, and are sericitised in places.

Section W8, of pebble from same locality as the preceding specimen. This is an intermediate type between the normal diabase and the spherulitic rock. Microscopically, it consists almost entirely of hornblende and felspar laths, with secondary chlorite. The long microlites of actinolite show the characteristic serrated edges, and the central tubular inclusion of the ground mass. One or two grains of the hornblende retain the rectangular cleavage of augite, clearly proving the secondary origin of the former mineral. The felspar laths are usually only simply twinned, and they are occasionally zoned. Extinction angles are generally low, but angles as great as 40° were measured on isolated sections. The felspar in places includes hornblende, and in others penetrates the femic mineral, showing that both minerals are essentially contemporaneous in origin. The chlorite is markedly pleochroic, in shades of green and yellow. One section gave an

1 "The Variolitic Rocks of Mont Genèvre." Q.J.G S., London, 1890, p. 330.

2 "Variolite of the Lleyn and associated Volcanic Rocks." Q.J.G.S., London, 1893, p. 155.

extinction angle of 7 degrees from the 001 cleavage. It is distinctly biaxial, having a fairly wide axial angle; is negative; and is referable to clinochlore. A little disseminated pyrites occurs throughout the section, and is associated with brown iron oxide. True spherulites are absent from the rock, but plumose aggregates of hornblende and felspar are common.

Section W5 is practically identical with W6, except that the spherulitic structure is not so well developed. Veinlets of quartz and chlorite, with a little brown oxide, traverse the rock.

Section W3, of a pebble from same locality as the foregoing specimens. Microscopically, the texture is aphanitic, with the exception of a few porphyritic crystals of felspar. These appear to be entirely calcic felspar, giving maximum extinction angles of 43° from the twin planes. The basis of the rock is not easily deciphered, but it appears to consist of plagioclase, grains of black iron oxide, and ? augite. Vesicles infilled with chlorite are rarely present. The rock is probably a basic volcanic, approaching a basalt.

Section W9, pebble in conglomerate, near steel bridge over Thomson River, is a highly chloritised, sericitised and carbonated rock, probably a diabase. Apparently both plagioclase and orthoclase are present in the section; chlorite (pennine) replacing ? femic mineral; quartz showing strain effects and a little biotite and ilmenite.

Summary.

A series of conglomerates, grits, and limestones, containing igneous pebbles and debris, occurs near the Thomson river, Walhalla. Certain previous explanations, of the origin of the conglomerate, and of the igneous material, appear to be unsatisfactory. It is shown that the explanation, which maintains that the conglomerate is derived by post Silurian faulting and brecciation of an accompanying dyke, is at variance with the field relations; and also that there is little evidence of vulcanicity contemporaneous with the deposition of the sediments. The writer concludes that the conglomerate is a normal marine shore line deposit, and that the igneous debris present in the conglomerates and limestones is derived from pre-existing igneous rocks.

Petrologically, the pebbles show considerable similarity. All intermediate stages between a hornblende diabase (epidiorite), and the spherulitic type of the same rock are represented in the

pebbles collected. Pebbles of hornblende gneiss, quartzite, limestone, slate, sandstone and chert are also present in the conglomerate.

EXPLANATION OF PLATE.

Plate II.

Fig. 1.—Microphotograph of hornblende diabase pebble, No. W2, showing two successive outgrowths from an idiomorphic felspar phenocryst. Ordinary light × 25.

Fig. 2.—Microphotograph of spherulitic diabase, No. W6. Ordinary light × 25.